RESTRICTED CIRCULATION

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AGRICULTURAL MEMORANDUM NO 790

Random Error Experiment

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1. Summary

This experiment, carried out at Kew Observatory during 1949, was designed to determine the random errors of observations under standard conditions. Four sets of instruments, including wet and dry bulb, maximum and minimum, grass minimum, 4 inch and 8 inch soil, and 1 ft. earth thermometers were set up over level grass with apparently identical 'standard' exposures. Readings were taken twice daily of all thermometers. The deviations of the readings of the four sets of instruments from the mean of the four were examined and the following results were obtained:-

Dry Bulb:	97.3% within ± 0.4°F.	(all hours)
Minimum:	95.4% within ± 0.3°F.	(0930)
Maximum:	95.4% within ± 0.5°F.	(1500)
Grass minimum:	95.7% within ± 1.6°F.	(0930)
Relative humidity:	96.8% within ± 2%	(all hours)
Dew Point:	95.9% within ± 0.9°F.	(all hours)
4 inch soil:	95.3% within ± 0.4°F.	(0930)
8 inch soil:	96.2% within ± 0.4°F.	(0930)
1 ft. earth	98.2% within ± 0.4°F.	(0930)

2. Conduct of the Experiment

Readings were taken of all thermometers at 0930h. and 1500h. Because it was impossible to take all readings simultaneously, the screens were read in a different order each week. The experiment was carried out over the following periods:-

Screen A	January 17th to July 7th.
Screens A, C, D.	January 17th to November 1st.
Soil, earth thermometers and grass minima	January 17th to Decemmber 24th.

No readings were taken on Sundays. Special care was taken to avoid perfect conditions, such as very frequent cutting of the grass, so that the experiment was carried out in a way comparable with an average station. Furthermore the experiment was not intended to analyse the rapid fluctuations of temperature that are known to take place in the air, but mainly to assess the differences involved in an arbitrary choice of site within the usual concept of a standard exposure.

The relative positions of the instruments (in a straight line) were A to B, 15 feet; B to C, 1 foot in echelon, C to D. 75 feet.

Manipulation of the Data

Several methods of summarising the data were tried; it was finally decided to adopt the following method:-

After the few obvious 5° and 10° errors had been eliminated, the mean of the four readings of each element was adopted as the correct or desired value. The deviations of the four values from the mean were then summarised.

The distribution of the deviations is given in the Appendix as follows:-

Table 1	Dry Bulb
" 2	Maximum and Minimum
" 3	Grass Minimum and Relative Humidity
" 4	Dew Point
" 5	4-inch Soil
" 6	8-inch Soil
" 7	1 ft. Earth

These statistics are summarised in Table 8.

Table 8

Element		Sample	S Dev	$\pm 2\sigma$	Percentage within $\pm 2\sigma$ range
Dry bulb	0930	882	0.19°F.	±0.4°F.	97.2
	1500	882	0.17°F.	±0.4°F.	97.6
	< 60°F	967	0.16°F.	±0.3°F.	95.6
	> 60°F	797	0.20°F.	±0.4°F.	96.6
	Total	1764	0.18°F.	±0.4°F.	97.3
Minimum	0930	870	0.16°F.	±0.3°F.	95.4
	1500	882	0.16°F.	±0.3°F.	95.6
	Total	1752	0.16°F.	±0.3°F.	95.5
Maximum	0930	870	0.31°F.	±0.6°F.	94.3
	1500	864	0.26°F.	±0.5°F.	95.4
	< 60°F	703	0.27°F.	±0.6°F.	96.5
	> 60°F	1031	0.29°F.	±0.6°F.	95.2
	Total	1734	0.28°F.	±0.6°F.	95.8
Grass Minimum	0930	1148	0.78°F.	±1.6°F.	95.7
	1500	1163	0.88°F.	±1.8°F.	94.9
	Total	2311	0.83°F.	±1.7°F.	94.9
Relative Humidity	0930	813	1.1%	±2%	97.2
	1500	882	1.1%	±2%	96.6
	Total	1695	1.1%	±2%	96.8
Dew Point	0930	310	0.33°F.	±0.7°F.	96.7
	1500	873	0.49°F.	±1.0°F.	95.2
	< 40°F	429	0.50°F.	±1.0°F.	95.2
	> 40°F	1254	0.41°F.	±0.8°F.	95.6
	Total	1653	0.42°F.	±0.9°F.	95.9
4 inch Soil	0930	1141	0.20°F.	±0.4°F.	95.3
	1500	1146	0.33°F.	±0.7°F.	96.8
	< 50°F	978	0.22°F.	±0.5°F.	95.9
	> 50°F	1308	0.31°F.	±0.6°F.	95.6
	Total	2286	0.27°F.	±0.6°F.	96.3
8 inch Soil	0930	1157	0.20°F.	±0.4°F.	96.2
	1500	1155	0.24°F.	±0.5°F.	95.9
	< 50°F	978	0.20°F.	±0.4°F.	94.6
	> 50°F	1334	0.23°F.	±0.5°F.	97.1
	Total	2312	0.22°F.	±0.5°F.	96.8

1 ft. earth	0930	1159	0.22°F.	±0.4°F.	95.7
	1500	1172	0.32°F.	±0.7°F.	95.3
	< 50°F	992	0.14°F.	±0.3°F.	98.3
	> 50°F	1339	0.34°F.	±0.7°F.	95.5
	Total ABCD	2331	0.27°F.	±0.6°F.	96.3
	Total BCD	1754	0.16°F.	±0.3°F.	96.4

Dry Bulb Readings

There is no great statistical difference in the distribution of deviations from readings taken at 0930 and 1500. There is, however, a significant difference between the sample below 60°F. and above, nevertheless the practical significance is not large.

Synoptic stations report temperatures in whole degrees, it is therefore important to calculate the percentages of occasions when this could be in error.

Table 9

(Temperatures below 60°F)

Observed Temperature Even number of whole degrees F plus	Range to give the same nearest whole number	Percentage of occasions 1° low (from Table 1)	1° high	Weighting Factor
0.0°F.	-0.4 to +0.4°F.	0.7	1.2	½
0.1°F.	-0.5 to +0.3°F.	0.4	2.3	1
0.2°F.	-0.6 to +0.2°F.	0.1	4.5	1
0.3°F.	-0.7 to +0.1°F.	-	10.3	1
0.4°F.	-0.8 to +0.0°F.	-	33.9	1
0.5°F.	0.0 to +1.0°F.	35.0	-	1
0.6°F.	-0.1 to +0.9°F.	12.6	0.2	1
0.7°F.	-0.2 to +0.8°F.	4.9	0.3	1
0.8°F.	-0.3 to +0.7°F.	2.1	0.3	1
0.9°F.	-0.4 to +0.6°F.	0.7	0.6	1
1.0°F.	-0.5 to +0.5°F.	0.4	0.8	½
	Weighted Sum	56.4	53.4	
Divide by 10 to derive	Average	5.6	5.3	

We can thus conclude that if the air temperature is below 60°F. eighteen out of twenty observations will be coded to the correct nearest degree. One will be 1° high and one 1° low. A similar calculation for temperatures above 60°F. gives the result:- 12 out of 14 correct, one 1° high, one 1° low.

Minimum Readings

As might have been expected, the minimum readings show less variance than the dry bulb readings and there is no significant difference between the sets of readings at 0930 and 1500.

Applying the analysis of Table 9 to the 0930 distribution we find that 5.1% of the readings are 1° low and 5.5% are 1° high, thus about 18 reports out of 20 give the "correct" result in terms of whole degrees.

Maximum Readings

The maximum thermometers were set at 0930 and 1500, in consequence the 0930 maximum was often the 1500 value the previous day. As the settings were not simultaneous this explains the greater variance of 0930 readings. The

scatter of 1500 readings is slightly greater than that of the dry bulbs.

If we consider the accuracy of the whole degree returns we see that 9% are 1° low, 8% 1° high and 0.2% 2° high. In general, therefore, eight out of ten readings are correct to the nearest whole degree, one is 1° high and one 1° low, only 1 in 500 is 2° high.

Grass Minimum Readings

These show a very great scatter indeed and it must be repeated that no special attempt was made to keep the exposure perfect. Grass was allowed to grow at times above the thermometer bulb and thus reproduce the effect of conditions at a normal imperfect station.

From this analysis about half the readings are correct to the nearest integer, 24.5% are 1° low, and nearly 3% 2° or 3° low, 17% are 1° high and over 4%, 2°, 3° or possibly 4° high.

Relative Humidity Readings

The readings at first glance show a surprising uniformity until it is realised that 1% relative humidity is a large unit compared with one tenth of a degree F. Over 87% of the readings are within 1% of the mean value, and nearly 97% within 2%.

Dew Point Readings

71% reported dew points are correct to the nearest degree, 14% are 1° or more high, 15% are 1° or more low. The full analysis is as follows:-

		1° low	Correct	1°high
Dew point	0930	12.1%	76.5%	11.4%
	1500	17.8%	66.5%	15.7%
	$<40^{\circ}$F	18.1%	65.7%	16.2%
	$>40^{\circ}$F	14.1%	73.1%	12.8%

The divergencies are most marked in the afternoon readings and when the dew point is low.

4 inch soil temperature readings

There is a distinct difference between the 0930 and 1500 distribution. The 0930 is near the time of minimum daily value and the 1500 near the time of daily maximum. The 0930 values are perhaps more uniform than might have been expected, about 97% lying within half a degree of the mean of the four. There is again evidence of an increase of variance with temperature, but to no great extent.

8 inch soil temperature readings

Similar considerations apply to the 8 inch readings, except that there is less extra scatter in the afternoon distribution and less change with increased temperature. Nearly 98% of the readings are within half a degree of the mean.

1 ft. earth temperature readings

At first glance it appears that the decrease with depth in point-to-point

variance of temperature which is as observed in comparing the 4 inch and 8 inch values has not continued in descending to 1 ft. However the distribution for temperatures below 50°F. is very much of the order that would have been expected and it was found that the large scatter of high temperatures was chiefly due to one site. If this site (A) is eliminated the distribution of the B, C, D values shows nearly 100% of the readings within half a degree of the mean. On examining the soil to a depth of 1 ft. at each of the sites it was found that B, C, D were in gravel, whilst the bottom 4 inch of the A site was clay.

Any comments or suggestions on this paper should be referred to the author.

Meteorological Office
Bracknell

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APPENDIX

Table 1

	Dry Bulb 0930	Dry Bulb 1500	Dry Bulb $< 60^{\circ}F$	Dry Bulb $> 60^{\circ}F$	Dry Bulb Total
-1.0					
-0.9					
-0.8		0.1		0.1	0.1
-0.7	0.2	0.1	0.1	0.3	0.2
-0.6	0.2	0.5	0.3	0.4	0.3
-0.5	0.7	0.6	0.3	1.0	0.6
-0.4	2.0	1.4	1.4	2.1	1.7
-0.3	3.4	3.5	2.8	4.3	3.5
-0.2	8.9	7.2	7.7	8.4	8.0
-0.1	22.9	22.7	22.4	23.2	22.7
0.0	23.1	29.0	31.1	25.4	28.5
+0.1	18.7	21.9	23.6	16.4	20.3
+0.2	8.1	6.4	5.8	9.2	7.3
+0.3	3.4	3.2	2.2	4.6	3.3
+0.4	1.7	2.3	1.1	3.0	2.0
+0.5	0.4	0.3	0.4	0.3	0.3
+0.6	0.3	0.6	0.2	0.7	0.5
+0.7	0.5	0.1	0.3	0.3	0.3
+0.8	0.0	0.1	0.0	0.1	0.1
+0.9	0.2		0.1	0.1	0.1
+1.0	0.3		0.2	0.1	0.2
Total	882	882	967	797	1764
σ	0.19	0.17	0.16	0.20	0.18
$\pm 2\sigma$	$\pm$0.4	$\pm$0.4	$\pm$0.3	$\pm$0.4	$\pm$0.4
Percentage within 2σ range	97.2	97.6	95.6	96.6	97.3

Table 2

Minimum 0930	Minimum 1500	Minimum Total	Maximum 0930	Maximum 1500	Maximum Total	Maximum $< 60^{\circ}F$	Maximum $> 60^{\circ}F$
				0.1	0.1		0.1
			0.7	0.0	0.3	0.1	0.5
0.1		0.1	0.2	0.1	0.2	0.0	0.3
0.0	0.2	0.1	0.9	0.5	0.7	0.7	0.7
0.3	0.1	0.2	2.0	0.9	1.4	0.7	1.9
0.7	0.7	0.7	1.7	1.2	1.4	1.0	1.7
0.9	1.4	1.1	2.9	3.4	3.1	3.6	2.8
2.5	2.6	2.6	6.4	6.0	6.2	6.8	5.8
6.7	6.7	6.7	11.4	9.5	10.4	9.7	11.0
19.7	22.7	21.1	16.2	20.7	18.4	19.4	17.8
36.0	35.7	35.8	20.2	22.6	21.4	22.5	20.6
20.8	18.5	19.6	16.1	15.8	15.9	18.2	14.3
7.6	6.7	7.1	9.7	8.5	9.1	8.3	9.6
2.1	2.7	2.4	3.1	4.1	3.6	2.4	4.4
1.4	0.5	0.9	1.7	2.4	2.1	1.9	2.2
0.4	0.7	0.5	1.9	1.4	1.7	1.6	1.7
0.3	0.3	0.3	0.9	1.0	1.0	0.4	1.4
0.3	0.2	0.3	0.9	0.4	0.6	0.3	0.9
0.0	0.2	0.1	1.3	0.7	1.0	1.1	0.9
0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2
0.1		0.1	1.5	0.8	1.1	1.1	1.2
870	882	1752	870	864	1734	703	1031
0.16	0.16	0.16	0.31	0.26	0.28	0.27	0.29
± 0.3	± 0.3	± 0.3	± 0.6	± 0.5	± 0.6	± 0.6	± 0.6
95.4	95.6	95.5	94.3	95.4	95.8	96.5	95.2

Table 3

^{o}F	Grass Minimum 0930	Grass Minimum 1500	Grass Minimum Total		Relative Humidity 0930	Relative Humidity 1500	Relative Humidity Total
-1.0	8.3	8.9	8.5				
-0.9	2.8	1.4	2.1				
-0.8	3.0	2.1	2.6				
-0.7	4.1	2.3	3.2	-7	0.1		0.1
-0.6	4.2	3.6	3.9	-6	0.1		0.1
-0.5	4.6	3.1	3.9	-5	0.1		0.1
-0.4	5.6	3.7	4.7	-4	0.0	0.5	0.2
-0.3	4.5	5.8	5.1	-3	0.9	1.2	1.1
-0.2	6.4	5.8	6.1	-2	3.1	5.9	4.6
-0.1	7.1	8.2	7.7	-1	24.1	20.6	22.3
0.0	6.3	10.9	8.7	0	45.9	41.2	43.5
+0.1	7.2	7.5	7.4	+1	20.3	22.9	21.6
+0.2	4.1	7.8	6.0	+2	3.8	6.0	5.0
+0.3	4.9	6.2	5.5	+3	1.0	0.9	0.9
+0.4	5.0	3.1	4.1	+4	0.3	0.7	0.5
+0.5	4.3	3.2	3.7	+5	0.2	0.0	0.1
+0.6	2.9	2.6	2.7	+6	0.1	0.1	0.1
+0.7	2.2	1.8	2.0				
+0.8	1.8	2.0	1.9				
+0.9	2.3	1.8	2.1				
+1.0	8.3	8.2	8.3				
Total	1148	1163	2311		813	882	1695
σ	0.78	0.88	0.83		1.1	1.1	1.1
$\pm 2\sigma$	$\pm$1.6	$\pm$1.8	$\pm$1.7		$\pm$ 2	$\pm$ 2	$\pm$ 2
Percentage within 2σ range	95.7	94.9	94.9		97.2	96.6	96.8

Table 4

	Dew Point 0930	Dew Point 1500	Dew Point $<40^{o}F$	Dew Point $>40^{o}F$	Dew Point Total
-1.0	0.6	3.2	3.0	1.6	2.0
-0.9	0.4	1.1	1.3	0.6	0.8
-0.8	0.4	2.5	1.9	1.4	1.5
-0.7	0.7	1.6	2.3	0.8	1.2
-0.6	2.1	2.2	2.8	1.9	2.1
-0.5	2.6	3.3	2.6	3.1	3.0
-0.4	5.3	3.8	4.7	4.5	4.5
-0.3	4.8	7.3	6.5	6.0	6.1
-0.2	11.6	8.7	9.6	10.3	10.1
-0.1	13.8	11.6	10.5	13.4	12.6
0.0	15.4	12.7	11.9	14.7	14.0
+0.1	14.1	9.3	9.1	12.4	11.6
+0.2	10.9	7.6	8.4	9.4	9.1
+0.3	5.1	5.5	6.8	4.8	5.3
+0.4	5.1	4.7	4.2	5.1	4.9
+0.5	2.1	3.0	2.1	2.7	2.5
+0.6	1.6	3.9	3.0	2.7	2.8
+0.7	1.5	1.8	1.9	1.6	1.7
+0.8	0.7	1.6	2.3	0.8	1.2
+0.9	0.5	1.3	2.1	0.5	0.9
+1.0	0.7	3.3	3.0	1.7	2.1
Total	810	873	429	1254	1683
σ	0.33	0.49	0.50	0.41	0.42
$\pm 2\sigma$	$\pm$0.7	$\pm$1.0	$\pm$1.0	$\pm$0.8	$\pm$0.9
Percentage within 2σ range	96.7	95.2	95.2	95.6	95.9

Table 5

	4 inch soil 0930	4 inch soil 1500	4 inch soil $< 50^{\circ}F$	4 inch soil $> 50^{\circ}F$	4 inch soil Total
-1.0	0.2	0.3	0.2	0.2	0.2
-0.9	0.1	0.3	0.2	0.2	0.2
-0.8	0.2	1.2	0.3	1.0	0.7
-0.7	0.3	1.4	0.4	1.2	0.9
-0.6	0.3	2.3	0.5	1.8	1.3
-0.5	0.9	4.2	1.2	3.5	2.5
-0.4	1.4	4.7	1.6	4.1	3.1
-0.3	3.2	5.4	3.3	5.2	4.2
-0.2	3.4	6.7	7.3	7.8	7.5
-0.1	21.6	14.9	21.5	15.9	18.4
0.0	31.0	18.0	31.0	19.6	24.4
+0.1	17.7	11.8	17.4	12.8	15.0
+0.2	5.8	7.7	5.8	7.6	6.8
+0.3	4.7	6.2	4.1	6.4	5.4
+0.4	1.5	5.4	1.4	5.0	3.4
+0.5	0.9	4.7	1.3	3.9	2.8
+0.6	0.7	2.3	0.8	2.0	1.5
+0.7	0.5	1.1	0.9	0.7	0.8
+0.8	0.4	0.8	0.5	0.7	0.6
+0.9	0.2	0.3	0.3	0.2	0.2
+1.0		0.3		0.2	0.1
Total	1141	1146	978	1308	2286
σ	0.20	0.33	0.22	0.31	0.27
$\pm 2\sigma$	$\pm$0.4	$\pm$0.7	$\pm$0.5	$\pm$0.6	$\pm$0.6
Percentage within 2σ range	95.3	96.8	95.9	95.6	96.3

Table 6

8 inch soil 0930	8 inch soil 1500	8 inch soil $<50^{\circ}F$	8 inch soil $>50^{\circ}F$	8 inch soil Total
0.1		0.1		
0.0		0.0		
0.0	0.1	0.0	0.1	0.1
0.3	0.3	0.4	0.3	0.3
0.5	0.5	0.8	0.3	0.5
0.9	1;7	0.7	1 6	1.3
2.6	3.9	2.0	4.2	3.2
4.5	5.9	3.6	6.4	5.2
8.5	10.8	8.9	10.2	9.6
18.6	18.3	21.4	16.3	18.4
25.6	22,6	29.6	20.0	24.1
21.3	15.6	18.2	18.0	18.4
9.7	7.6	5.7	10.8	8.7
4.5	5.1	3.8	5.5	4.8
0.9	2.7	1.4	2.1	1.8
0.8	1.7	1.2	1.4	1.3
0.6	1.6	1.3	0.9	1.1
0.4	1.1	0.7	0.8	0.8
0.1	0.2	0.1	0.2	0.2
0.1	0.3	0.1	0.3	0.2
1157	1155	978	1334	2312
0.20	0.24	0.20	0.23	0.22
$\pm$0.4	$\pm$0.5	$\pm$0.4	$\pm$0.5	$\pm$0.5
96.2	95.9	94.6	97.1	96.8

Table 7

	1 foot earth 0930	1 foot earth 1500	1 foot earth $<50^{\circ}F$	1 foot earth $>50^{\circ}F$	1 foot earth A,B,C,D Total	1 foot earth B,C,D, Total
-1.0	0.1	2.2		2.0	1.2	
-0.9	0.1	0.7		0.7	0.4	
-0.8	0.3	1.0		1.1	0.7	
-0.7	0.4	0.9		1.1	0.7	0.1
-0.6	0.6	1.3	0.1	1.6	0.9	0.0
-0.5	1.2	1.4	0.2	2.1	1.3	0.3
-0.4	2.1	1.3	0.7	2.4	1.7	2.0
-0.3	4.0	3.8	2.9	4.6	3.9	5.0
-0.2	10.3	6.6	8.9	8.1	8.4	9.3
-0.1	16.6	14.2	21.0	11.2	15.3	15.9
0.0	23.9	21.8	32.4	15.8	22.8	30.0
+0.1	21.7	18.2	23.3	17.4	19.8	23.4
+0.2	9.2	10.9	6.6	12.8	10.1	9.4
+0.3	5.8	7.3	3.2	9.1	6.6	3.4
+0.4	2.1	3.8	0.7	4.6	3.0	1.0
+0.5	1.3	2.0		2.9	1.7	0.1
+0.6	0.2	1.4		1.3	0.8	0.1
+0.7	0.1	0.4		0.5	0.3	
+0.8		0.5		0.4	0.3	
+0.9		0.2		0.2	0.1	
+1.0		0.1		0.1		
Total	1159	1172	992	1339	2331	1754
σ	0.22	0.32	0.14	0.34	0.27	0.16
$\pm 2\sigma$	$\pm$0.4	$\pm$0.7	$\pm$0.3	$\pm$0.7	$\pm$0.6	$\pm$0.3
Percentage within 2σ range	95.7	95.3	98.3	95.5	96.3	96.4